AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 100:341–354 (1996)

Estimating Diaphyseal Length From Fragmentary Subadult Skeletal Remains: Implications for Palaeodemographic Reconstructions of a Southern Ontario Ossuary

ROBERT D. HOPPA AND KATHERINE L. GRUSPIER
Department of Anthropology, McMaster University, Hamilton, Ontario, Canada L8S 4L9 (R.D.H.) and Department of Anthropology, University of Toronto, Toronto, Ontario, Canada M5S 1A1 (K.L.G.)

KEY WORDS Subadult, Long bone, Aging, Demography, Ossuary, Regression

ABSTRACT Fragmentary skeletal remains are a significant problem for osteologists attempting to reconstruct individuals or populations. This problem is further aggravated by sites yielding commingled remains, such as are recovered from the large protohistoric and historic ossuaries from southern Ontario, for which individual methods of age estimation and sex determination cannot be used concurrently. While some attention has been given to the estimation of long bone length from fragmentary, adult remains, little attention has been given to the equally important problem of fragmentary long bones in subadult assemblages. Analysis of data on diaphyseal length is a crucial aspect of reconstructing subadult palaeodemographic profiles, particularly for ossuary collections where dental remains are not associated with individuals and are often less represented than long bones. Such analysis also aids in the assessment of conditions of past population health. This study reports the results of several regression techniques used to estimate diaphyseal length from shaft-end breadths. Data collected from two southern Ontario ossuary samples were compiled to calculate the regression equations. Reliability of these equations and implications for palaeodemographic profiles are discussed.

The collection and analysis of data on diaphyseal length from subadult remains has two purposes. First, a variety of genetic and environmental influences, including malnutrition and disease, affect growth. As a result, skeletal growth profiles constructed from subadult long bone data can serve as nonspecific indicators of general health within a population (e.g., Stewart, 1954; Johnston, 1962; Walker, 1969; Merchant and Ubelaker, 1977; Sundick, 1978; Molleson, 1989; Lovejoy et al., 1990; Saunders and Melbye, 1990; Wall, 1991; Hoppa, 1992; Saunders et al., 1993; Miles and Bulman, 1994; Ribot and Roberts, 1996). Second, while the utilization of data on diaphyseal length to estimate individual ages can be problematic (Hoppa, 1992; Ubelaker, 1987), in some circumstances, such as the large protohistoric ossuaries of southern Ontario, age estimation based on diaphyseal length is one of the few methods available for reconstructing subadult demographic profiles. A number of investigators have noted that when correlated with a good estimator of chronological age such as dental development, estimates of age based on diaphyseal length are the most reliable when dental data are absent (Hoffman, 1979; Sundick,

Received November 28, 1994; accepted December 29, 1995.

Address reprint requests to Robert D. Hoppa, Department of Anthropology, McMaster University, 1280 Main St. West, Hamilton, Ontario, Canada L8S 4L9.

1978; Ubelaker, 1989). Of course, all investigators would admit that such estimates are not as simple as this statement might suggest. The use of an appropriate skeletal growth profile must be selected on which to estimate age from diaphyseal length. However, built into such profiles are errors related to (1) variability in the timing of maturation within individuals and (2) environmental and genetic factors which can differentially influence the rate of growth and maturation in different populations (Hoppa, 1992). Ideally, all individuals should be included in demographic reconstructions so that the best representation of the individuals per age is attained. Unfortunately, such reconstructions are often based solely upon complete specimens, with fragmented remains used only to estimate a minimum number of individuals (MNI) within the sample.

Whether these sample profiles are representative of the population is a theoretical question that has undergone much debate recently (Hoppa, 1996; Saunders and Hoppa, 1993; Wood et al., 1992) and is not the focus of this paper. Underrepresentation, especially of infants and neonates, within skeletal samples as a result of differential preservation, burial practices, and excavation techniques has been a central focus of criticism within palaeodemographic reconstructions. It has been argued that the fragile nature of subadult skeletal material often makes for poor preservation in ossuary remains, which further reduces an often underrepresented cohort of the population (Kapches, 1976). As such, the younger the individual the more likely that the age cohort of that individual will not be representative of the general population (Johnston and Zimmer, 1989). However, "factors such as *differential burial practices and inexperience on the part of excavators* can prove more important to subadult skeletal preservation than differential tissue survival" (Saunders, 1992:2).

Although some attention has been given to the estimation of adult long bone length from fragmentary or incomplete remains (Steele and McKern, 1969; Simmons et al., 1990), little attention has been given to the equally important problem of fragmented long bones in subadult assemblages (Gruspier and Hoppa, 1993; Hoppa, 1992). This report provides a method to estimate complete diaphyseal length from either the proximal or distal end of incomplete subadult long bones, and examines the implications of this technique for the subadult demographies of prehistoric southern Ontario ossuaries.

MATERIALS AND METHODS

The primary data for this study were derived from two late Woodland, ossuary samples from southern Ontario: Kleinburg (MNI = 561; Pfeiffer, 1974, 1980) and Fairty (MNI = 512; Anderson, 1964). The Fairty ossuary is dated by association with the Robb site to between 1300 and 1350 A.D. (Kapches, 1981), although recent C^{14} results from the skeletal remains suggest an earlier date (Gruspier, 1996). The Kleinburg ossuary is dated by grave goods to 1580 to 1600 A.D. (Kenyon and Kenyon, 1983). Two smaller samples were used to test the cross-sample applicability of the regression equations: one is culturally and temporally similar to the reference samples, the other is not. The first is the Uxbridge ossuary, which dates from the late Woodland period of southern Ontario prehistory, falling temporally between Fairty and Kleinburg at 1490 ± 80 A.D. (Pfeiffer, 1984). The second is from the cemetery site of Cosa, located in southern Tuscany on the west coast of Italy. The remains sampled for this study derive from the early medieval cemetery, tentatively dated to between the eighth and 10th century A.D. (Gruspier, 1994).

Both collections were thoroughly searched for all complete and fragmentary humeri and femora that exhibited unfused epiphyseal ends. Tibiae and radii were additionally sorted from the Kleinburg sample only. Neither of the collections had been previously fully mended, therefore this procedure was necessary before further analysis could proceed. Measures of proximal and distal shaft-end breadths were recorded for the humeri, radii, femora, and tibiae. Bones for each collection were sorted and grouped by side and preservation. Fragmentary remains were subdivided into proximal and distal frag-

ments for enumeration, and each specimen was checked for mends with all other fragments. This procedure was repeated for each bone. Diaphyseal lengths of all complete specimens were measured to the nearest millimeter using a standard osteometric board. Diaphyseal shaft-end breadths were recorded to the nearest tenth of a millimeter using Mitutoyo Digimatic calipers accurate to ±0.02 mm. All measures were recorded independently by both authors to examine interobserver error and the reproducibility of the measurements. Definitions for each measure are as follows.

Humerus

Proximal shaft breadth. Holding the bone vertically with the proximal end up, and the caliper at a right angle to the shaft, place the fixed arm of the caliper *flush against the edge of the greater and lesser tubercles* and measure to the opposite edge.

Distal shaft breadth. Holding the bone vertically with the distal end up, and the caliper with the arms pointing downward, measure the maximum horizontal distance between the medial and lateral edges of the distal surface.

Radius

Proximal shaft breadth. Holding the bone vertically with the proximal end up, and the caliper at a right angle to the shaft, take a *maximum* diameter of the surface.

Distal shaft breadth. Holding the bone vertically with the distal end up, and the caliper at a right angle to the shaft, place the fixed arm of the caliper flush against the edges of the ulnar notch and take a measure to the opposite edge of the surface.

Femur

Vertical head diameter. This measure is a sagittal head diameter analogous to the measure taken on adult femora.

Mediolateral neck breadth. An additional measurement was obtained from the proximal femur in the Kleinburg sample, representing a maximum breadth, parallel to the shaft, from the growth surface of the head to the most lateral edge of the unfused greater trochanter. This is *not* an oblique distance.

Distal shaft breadth. While holding the bone vertically with the distal end up, and the caliper at a right angle to the shaft, measure the maximum horizontal distance between the medial and lateral edges of the distal surface.

Tibia

Proximal shaft breadth. While holding the bone vertically *in anatomical position,* with the proximal end up, and the caliper at a right angle to the shaft, measure the direct horizontal distance between the medial and lateral edges of the proximal surface. This is not necessarily a maximum breadth.

Distal shaft breadth. Holding the bone vertically with the distal end up, and the caliper at a right angle to the shaft, place the fixed arm of the caliper flush against the edge of the fibular notch and take a measure to the opposite edge of the surface.

Initial analysis of the data included tests of equality for both sides and samples, as well as assessments of interobserver error for all the measurements. Following this the data were subjected to regression analysis. Linear and nonlinear models for estimating diaphyseal length from shaft-end breadths were tested for each measurement. Reliability of the estimates was examined through an analysis of residuals and by testing the equations on samples of complete bones. The final equations were then applied to a sample of incomplete long bones to estimate diaphyseal lengths. These estimates were then used to generate new subadult palaeodemographic profiles in both samples, utilizing the Arikara skeletal growth profiles (Merchant and Ubelaker, 1977). In order to test whether the equations are applicable for use in estimating diaphyseal length in other populations, they were applied to a sample of complete humeri from the Uxbridge ossuary, and humeri and femora from Cosa. The predicted lengths were then compared to the actual lengths of the diaphyses using paired samples t tests.

TABLE 1. Sample sizes and correlation coefficients between each measurement and diaphyseal length[1]

		Diaphyseal length	Prox1		Prox2		Dist1	
			N	r	N	r	N	r
Humerus								
Fairty	Left	88	77	0.9848			81	0.9823
	Right	90	82	0.9858			86	0.9838
	Combined	178	159	0.9854			167	0.9830
Kleinburg	Left	64	57	0.9438			58	0.9409
	Right	62	57	0.9570			54	0.9710
	Combined	126	114	0.9503			112	0.9557
	Total	304	273	0.9795			279	0.9789
Radius								
Kleinburg	Right	43	40	0.9741			30	0.9596
Femur								
Fairty	Left	89	70	0.9912			69	0.9813
	Right	86	64	0.9872			57	0.9721
	Combined	174	134	0.9887			126	0.9773
Kleinburg	Left	46	39	0.9787	38	0.9896	38	0.9515
	Right	43	33	0.9791	37	0.9886	32	0.9199
	Combined	89	72	0.9787	75	0.9891	70	0.9379
	Total	263	206	0.9869			196	0.9696
Tibia								
Kleinburg	Left	50	33	0.9777			35	0.9752
	Right	56	34	0.9754			38	0.9776
	Combined	106	67	0.9737			73	0.9766

[1] All correlations are significant at $P < 0.0001$.

TABLE 2. Independent t*-tests for sides and samples*

	N (L/R)	Mean diff. (mm)	SE mean diff.	t	df	2-tail sig.
Left vs. right						
Kleinburg						
Humerus	64/62	−3.6820	7.997	−0.46	124	0.646
Femur	46/43	14.7139	18.892	0.78	87	0.438
Tibia	50/56	−15.0086	14.104	−1.06	104	0.290
Fairty						
Humerus	88/90	−4.6707	9.136	−0.51	176	0.610
Femur	89/86	3.0865	15.578	0.20	173	0.843
Fairty vs. Kleinburg (sides combined)						
Humerus	178/126	−49.2728	6.055	−8.14	301.54[1]	<0.001
Femur	175/89	−63.9887	12.208	−5.24	201.27[1]	<0.001

[1] Levene's test for equality of variances $P < 0.05$.

RESULTS

Table 1 presents the sample size for each measurement in the two ossuaries, as well as Pearson's correlation coefficients for each measurement with diaphyseal length, (PROX1 = proximal shaft-end breadth; PROX2 = neck length of femur; DIST1 = distal shaft-end breadth). Correlation coefficients calculated on each side independently result in slightly but not significantly higher r values. Independent t tests comparing both sides and samples for each measurement are presented in Table 2. While all measurements had comparable distributions for each side, comparison of the samples reveals that Kleinburg has consistently larger mean values for each measurement.

Interobserver error was tested for each measure and the results are presented in Table 3. Paired samples t tests were used to evaluate the closeness of fit between each measurement for each author. The results suggest that some of these measurements are highly reproducible, but for others it is more difficult to obtain consistent results between observers.

Several regression models were applied to the data to derive prediction equations for diaphyseal length from measurements of shaft-end breadths. The complete diaphyses,

TABLE 3. Interobserver error[1]

Bone	Measurement	N	Corr.	2-tail sig.	Mean diff. (mm)	SE mean diff.	t	df	2-tail sig.
Femur									
	PROX1	67	0.998	<0.001	0.2582	0.060	4.29	66	<0.001
	PROX2	77	0.999	<0.001	−0.0221	0.074	−0.30	76	0.765
	DIST1	85	0.999	<0.001	0.1482	0.044	3.40	84	0.001
Humerus									
	PROX1	181	0.998	<0.001	0.0127	0.038	0.034	180	0.737
	DIST1	181	0.993	<0.001	0.0088	0.059	0.15	180	0.881
Tibia									
	PROX1	123	0.999	<0.001	0.0154	0.053	0.29	122	0.773
	DIST1	118	0.998	<0.001	0.1153	0.045	2.56	117	0.012

[1] Paired samples t test for each measure and bone.

TABLE 4. Linear regression models and statistics[1]

Bone	Measurement	N	R^2	Adj. R^2	s_e (mm)	F	Signif F	Constant	β_1
Femur									
	PROX1	205	0.97397	0.97384	17.00085	7632.08564	<0.0001	−39.566889	11.078994
	PROX2	74	0.97824	0.97794	12.55510	3281.15766	<0.0001	−70.276137	4.935822
	DIST1	195	0.94021	0.93990	24.78380	3050.48616	<0.0001	−41.059877	5.959925
Humerus									
	PROX1	272	0.95948	0.95933	12.17259	6416.56373	<0.0001	−19.624508	8.113157
	DIST1	278	0.95834	0.95819	12.24649	6371.49155	<0.0001	−31.555209	5.971567
Radius									
	PROX1	39	0.94880	0.94745	9.96877	704.11793	<0.0001	−27.038659	13.432445
	DIST1	29	0.92077	0.91794	13.15042	325.41150	<0.0001	−31.721254	9.561292
Tibia									
	PROX1	66	0.94800	0.94720	16.53400	1184.92399	<0.0001	−43.848220	6.126475
	DIST1	72	0.95381	0.95316	16.34698	1466.29196	<0.0001	−58.862430	10.307365

[1] Adjusted $R^2 = R^2 - \frac{K-1}{n-K}(1 - R^2)$ takes into consideration the complexity of the data compared to the complexity of the model (Hamilton, 1992) and provides a more realistic estimate of how well the model fits the population (Norušis, 1993). Goodness of fit for the equations is asessed by the residual standard deviation, $s_e = \sqrt{\frac{RSS}{n-K}}$, where n is the sample size and K is the number of parameters.

sides pooled, for both samples were combined. The regression equations and their test statistics are presented in Table 4. Graphs were generated to illustrate the relationship between diaphyseal length and each of the shaft-end breadths. Figures 1–3 illustrate the relationship between diaphyseal length and each measurement for the femora and humeri, with linear regression lines and their 95% *prediction intervals* overlaid. All measurements demonstrated a strong correlation with diaphyseal length, exhbiting a near-linear or slightly curvilinear distribution. Goodness of fit statistics and residuals were examined to test the validity of the linear models. Figure 4 presents a residual plot for one of the equations. The results of these suggested that samples which contain a considerable number of neonatal/fetal remains are better fitted by a polynomial equation (Fig. 5).

Testing the accuracy of these models for other population samples was conducted by applying the regression equations to a small sample of complete bones from the Uxbridge ossuary and the Medieval Italian cemetery at Cosa. The results of the paired samples t tests used to evaluate the degree of deviation between the observed and predicted lengths are presented in Table 5.

Subadult palaeodemographic profiles were subsequently generated from the long bone sample, including both complete and estimated diaphyseal lengths. Individuals were placed in 1 year age categories by length, based on the Arikara skeletal growth profiles (Merchant and Ubelker, 1977). The refined mortality distribution for the Fairty ossuary, including fragmentary remains, is presented in Figure 6. This demographic profile is based on the right humerus with fragmentary lengths estimated from distal

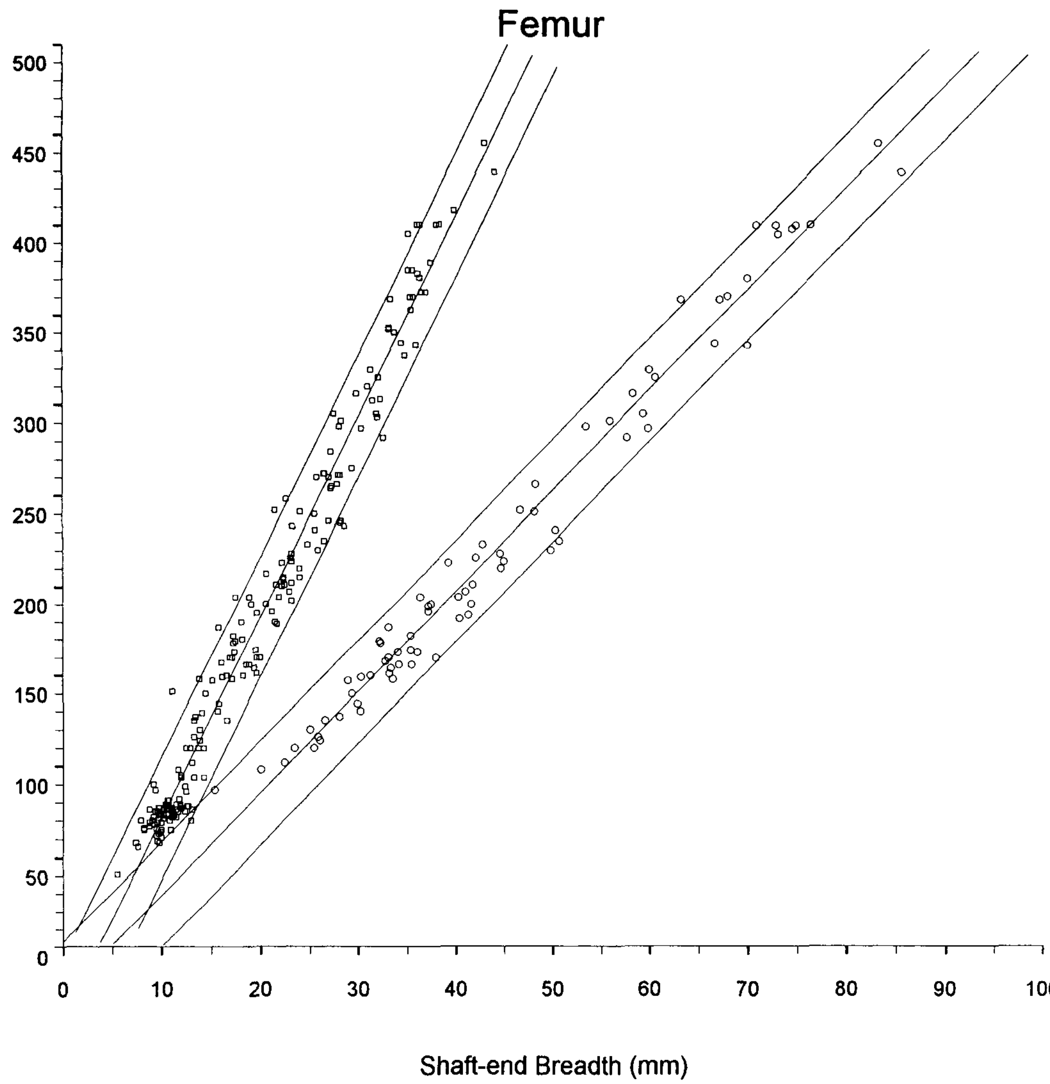

Fig. 1. Scattergram of shaft-end breadths for the femur (PROX1, squares; PROX2, circles) vs. diaphyseal length. Linear regression lines of the form $Y = \beta_0 + \beta_1 X$ and 95% prediction intervals are overlaid.

shaft-end breadths. Inclusion of individuals represented only by incomplete long bones increased the sample size by over 100%.

DISCUSSION

To estimate complete lengths from fragmentary remains, it is important that accurately recognizable landmarks be used. As a result, the measures used to develop regression models for diaphyseal length are limited. Measures of breadth along the shaft are inappropriate as differential fragmentation may prevent or inhibit proper and accurate identification. Therefore, the only remaining locations suitable for measurements on fragmentary remains are the epiphyses and the ends of the diaphyses or metaphyseal regions. Since ossuary collections are not normally conducive to associating bones for unique individuals, the use of epiphyseal measures is not universally applicable, although it can be done (Hoppa,

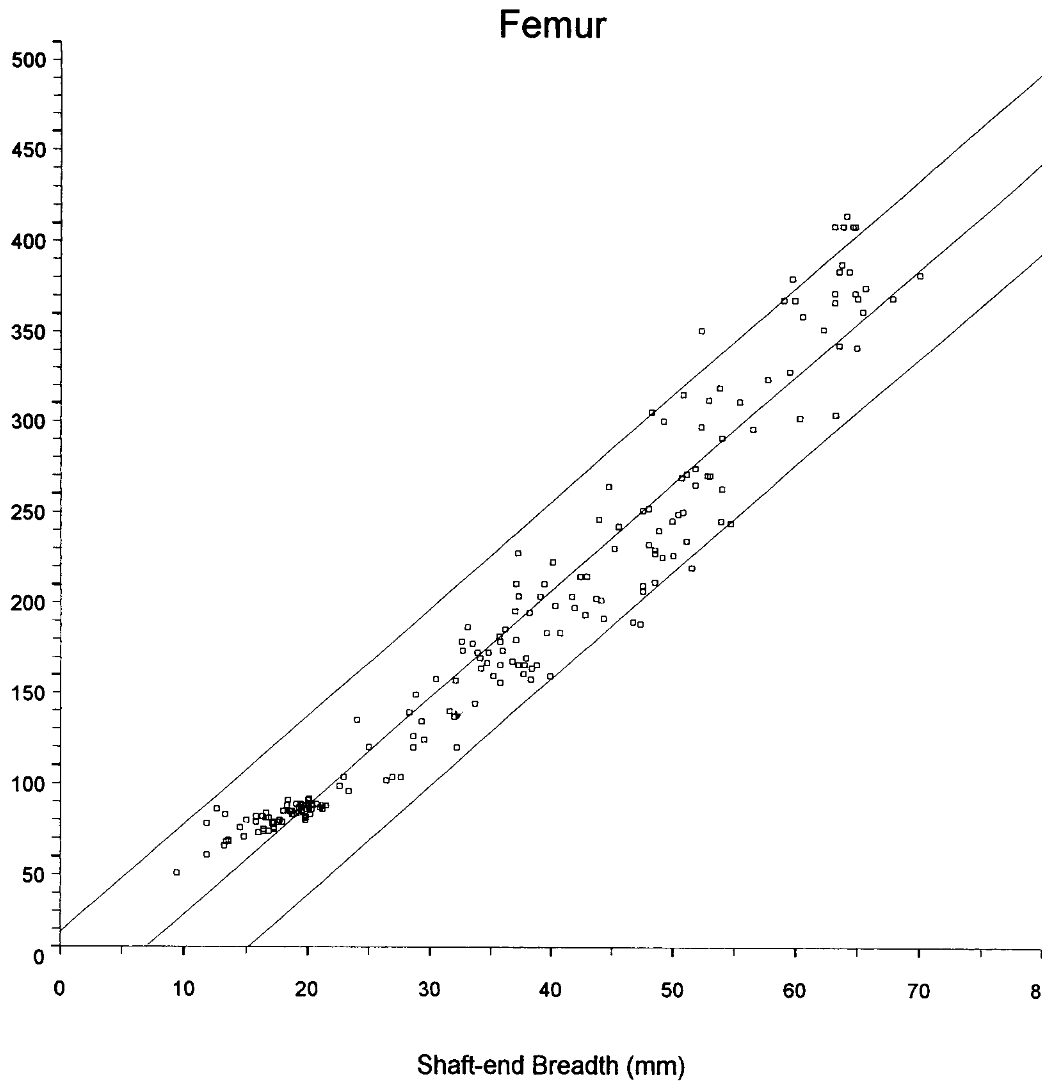

Fig. 2. Scattergram of proximal shaft-end breadth for the femur (DIST1) vs. diaphyseal length. Linear regression line of the form $Y = \beta_0 + \beta_1 X$ and 95% prediction intervals are overlaid.

1992). The results for interobserver error in Table 3 indicate that some of the measures are less reproducible than others. However, given that all measures were taken only to the nearest tenth of a millimeter, and that the mean difference is always less than this level of precision, the difference is of no consequence either practically or theoretically (Brown and Rothery, 1993).

As with any statistical procedure, there are a number of assumptions built into ordinary least squares regression analysis that should be addressed. Since most of these assumptions focus on error (omitted variables, a nonlinear relationship, nonconstant error variance, correlation among errors, nonnormal errors, or influential cases), residual analysis is one way of assessing these problems. Normal probability plots of residuals and scatter plots of predicted values vs. residuals aid in assessing the validity of these assumptions (Hamilton, 1992). Figure 4 presents a residual scattergram for one of the regression equations presented here. It

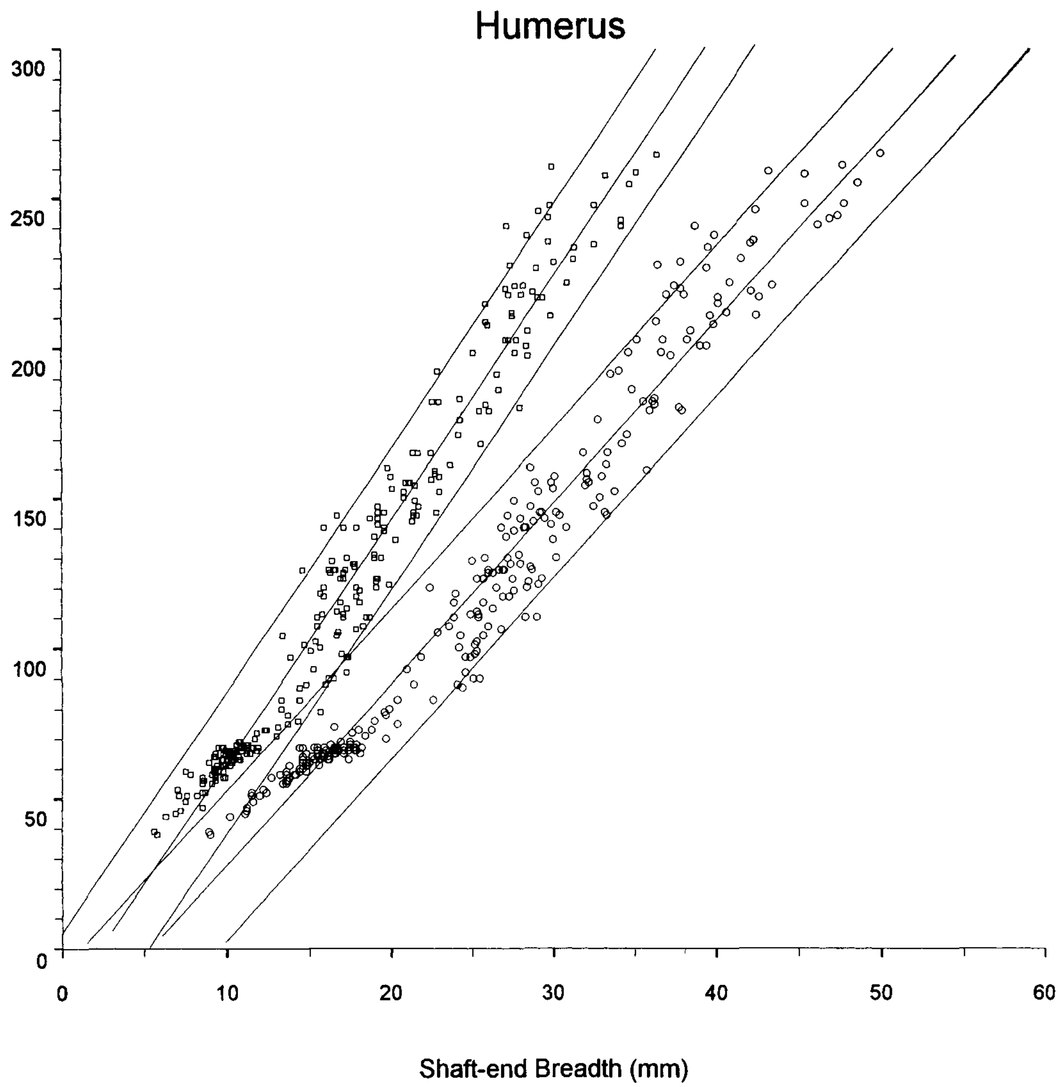

Fig. 3. Scattergram of shaft-end breadths (PROX1, squares; DIST1, circles) for the humerus vs. diaphyseal length. Linear regression line of the form $Y = \beta_0 + \beta_1 X$ and 95% prediction intervals are overlaid.

is clear from this graph that the error is normally distributed and relatively homoscedastic (the magnitude of error is constant), and there are no influential cases. The slightly nonnormal distributions of neonates, as denoted by the majority being found with negative residuals, does suggest a slightly nonlinear relationship with the inclusion of very young individuals. For the humerus this was more apparent as a result of increased numbers of perinatal humeri being included in the sample. As a result, second and third order polynomial models were also generated which more precisely modeled the relationships (Fig. 5). The overall residual standard deviation (s_e) for these models is not significantly reduced since the residuals tend to be improved only in the very small perinatal remains. For the majority of the sample, the scatter around the regression line remains essentially the same as the simple linear equation.

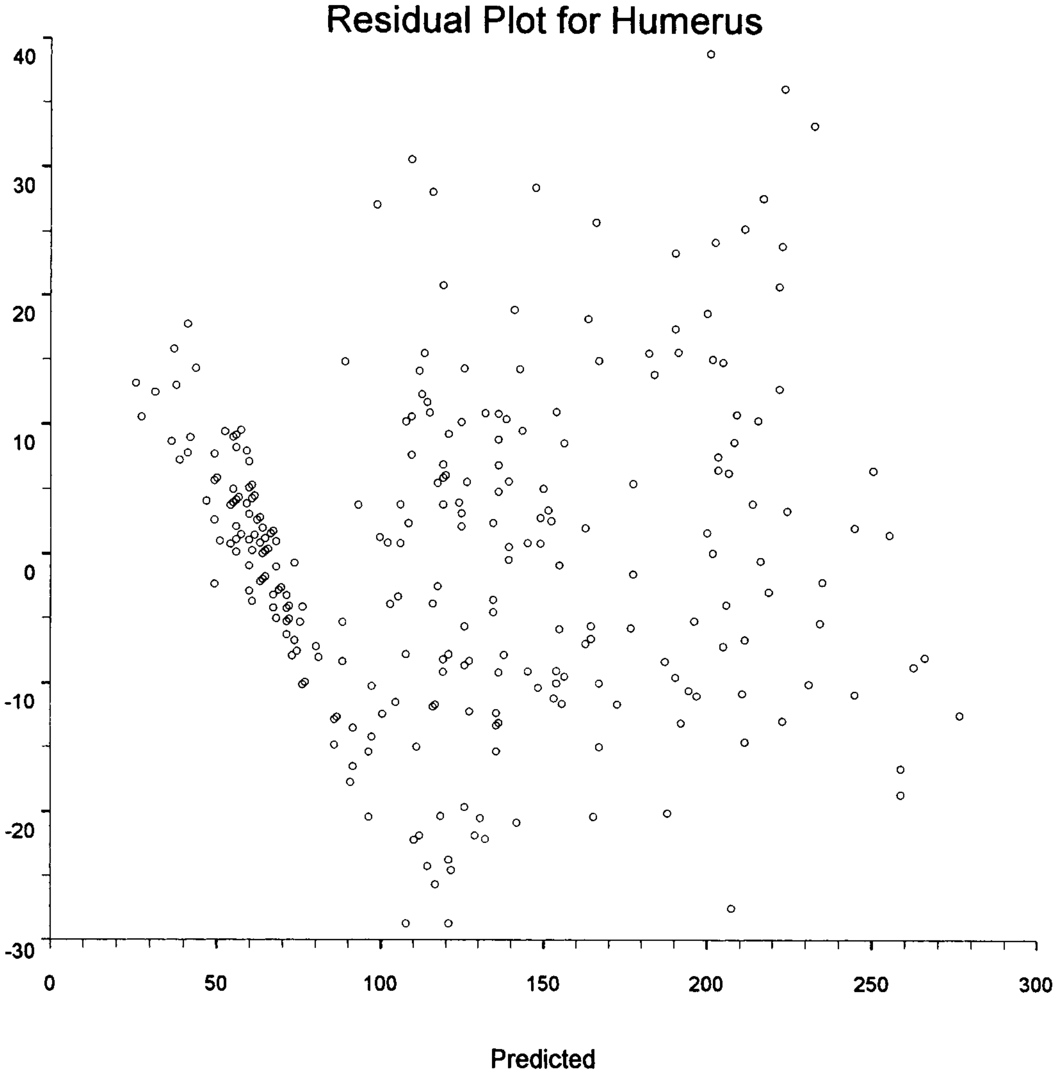

Fig. 4. Residual plot for the linear regression equation for humerus (PROX1). The plot shows a relatively random distribution of error with the exception of the very small bones, which tend to be consistently underestimated by the linear equation.

An earlier study of this method (Hoppa, 1991) assumed that the process of bone growth would be similar within any human subadult series regardless of ethnic or cultural origins, and that such data could be pooled to derived an overall relationship between the various measures. This initial study included subadults from both a 10th century A.D. Anglo-Saxon collection and a 4th–5th century A.D. Romano-British collection, and found reasonably good correlations between shaft and epiphyseal breadth and diaphyseal length (r values ranging from 0.86 to 0.96). However, subsequent separation and independent examination of the two samples revealed significant differences, with the extraction of the Roman remains increasing the correlation coefficients for the Anglo-Saxon sample. This suggested that differences between samples may be significant and that population-specific models might be necessary to make accurate use of

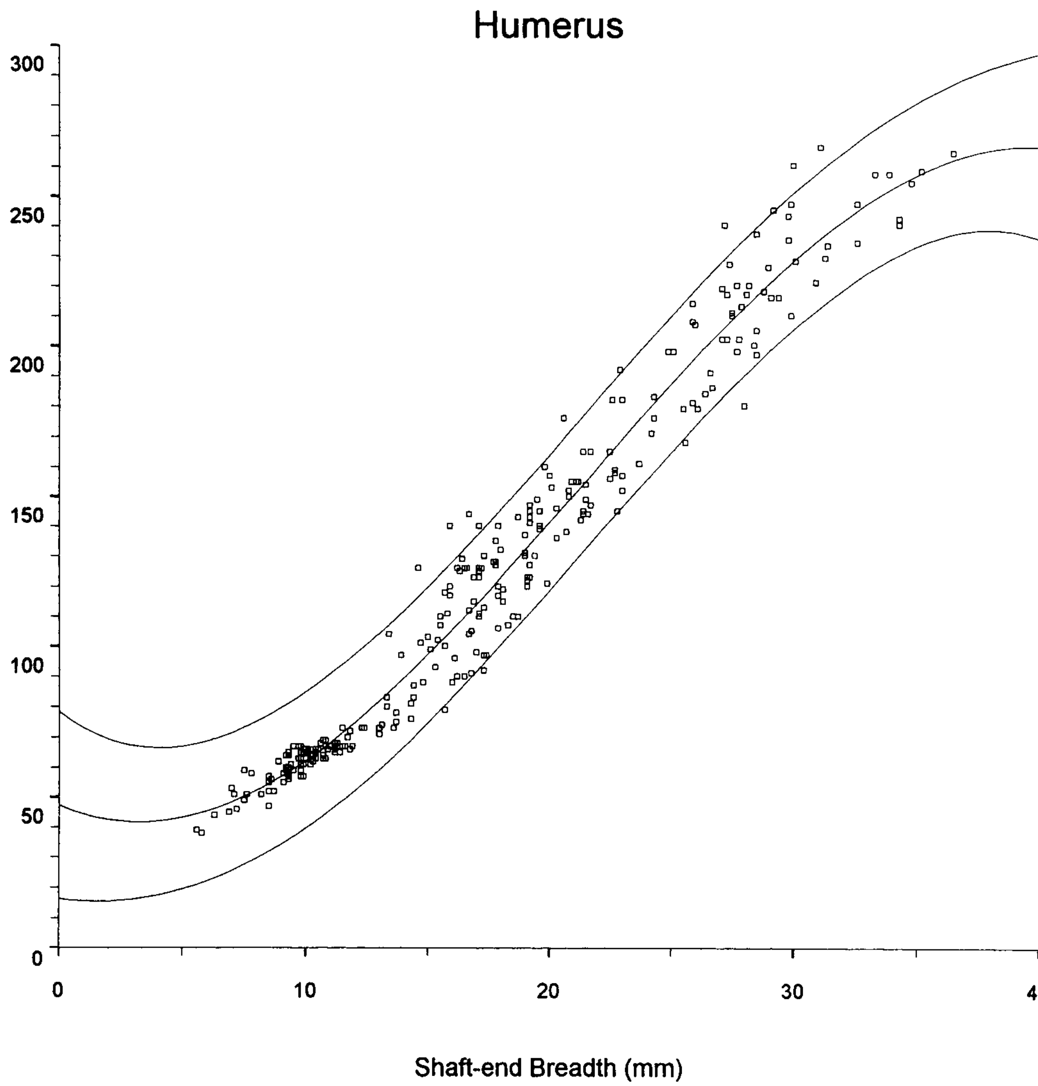

Fig. 5. Scattergram of distal shaft-end breadth for the humerus (PROX1) vs. diaphyseal length. Cubic regression line of the form $Y = \beta_0 + \beta_1X + \beta_2X^2 + \beta_3X^3$ and 95% prediction intervals are overlaid.

TABLE 5. Paired samples t *tests of observed vs. estimated diaphyseal length*

Bone	Estimator	Mean diff. (mm)	SD diff.	*t*	df	*P*
Uxbridge						
Humerus	Prox1	−3.237	11.392	−1.927	45	0.060
	Dist1	−4.908	9.279	−3.777	50	<0.001
Cosa						
Humerus	Prox1	3.006	14.776	0.839	16	0.414
	Dist1	−5.056	12.661	−1.597	15	0.131
Femur	Prox1	−24.305	35.692	−2.968	18	0.008
	Dist1	−13.720	29.089	−2.109	19	0.048

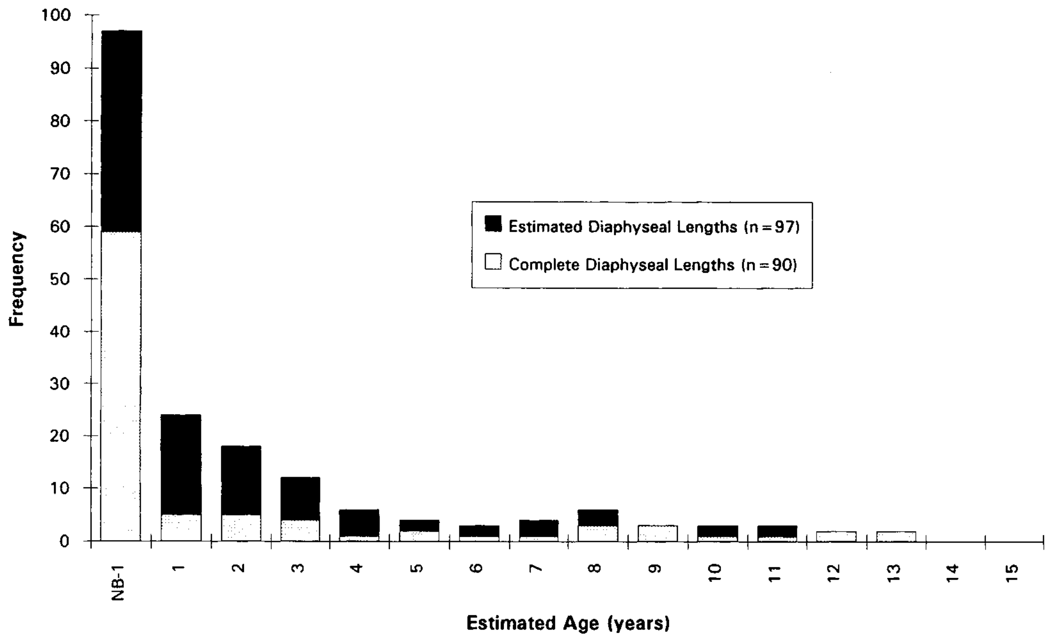

Fig. 6. Subadult demographic profile for Fairty, illustrating the impact of the inclusion of individuals represented by fragmentary remains. The demography is based on the right humerus, with fragmentary remains estimated from distal shaft-end breadths.

these methods. This finding is supported by this study, which observed significant differences between the two late Woodland samples, due primarily to the preponderance of perinatal remains in the Fairty sample. Despite this, the samples and sides were pooled for the final presented equations, since examination of residuals for side- and site-specific equations applied to their complementary holdout sample produced error distributions comparable to that observed using the combined-samples equations. That is, the actual level of predictability did not significantly improve when using a single reference sample. The final equations were also tested on two small samples of complete bones: one southern Ontario sample and one Medieval Italian sample. The results of the intersample tests for accuracy are not that surprising. Despite being relatively close in temporal and cultural affiliation to the reference sample, prediction on the Uxbridge sample produced mixed results, with significant or near-significant differences observed. The fact that for the Cosa sample the predicted humeri lengths are not significantly different from the observed lengths, while the femora are, suggests that differential growth in the limbs for different populations may further complicate interpretation of the results. Another factor to be considered is the general level of health within populations, particularly those childhood conditions which can affect growth. For example, in the Cosa sample almost all of the subadults exhibit multiple indicators of nonspecific stress (Gruspier, 1994). In fact, it would be of interest to explore whether or not application of these equations to other samples of complete bones could be used to identify individuals that are pathological. Given that interruptions in the growth process tend to affect the overall length of a bone and not the width at the ends, large deviations between predicted and observed lengths may suggest this. Although the application of our equations does seem to produce estimated lengths that do not always differ significantly from known lengths in both samples, we would still encourage other

investigators to create their own sample equations when possible.

The potential of this technique for maximizing the sample size of the subadult cohorts is clearly illustrated in Figure 6. The profile created for the Fairty ossuary shows an increase in sample size by over 100% when the estimated diaphyseal lengths are included. An earlier study (Larocque, 1991) reports that, for the Fairty ossuary, 43% of the total sample of 512 individuals are less than 20 years of age, and of those 35%, or about 77 individuals, are under 3 years of age based on the tibiae. In the present study, we find a comparable count (n = 72) of individuals under 3 years of age based on the complete humeri (right side only). However, the inclusion of the fragmentary humeri results in an *additional* 97 under 15 years of age. Most importantly, the greatest increase is seen in the under-5-year-olds, which represent the age cohort most useful in interpreting the overall health of a population. Ironically, it is this cohort that is most often statistically manipulated (Jackes, 1986; Melbye, 1984) or simply ignored (Jackes, 1994) in demographic analyses of southern Ontario ossuaries. This circumstance is due in part to the misperception that *all* southern Ontario ossuaries are lacking in infant skeletal remains (e.g., Jackes, 1994; Kapches, 1976; Katzenberg and White, 1979; Sutton, 1988). However, in their paper, Saunders and Spence (1986) discuss underrepresentation specifically with regard to late fetal and perinatal infants. With regard to postneonatal infants, "presumably, the bulk of infants dying during the postnatal period were buried in the ossuary" (1986:52).

Although we recognize that there may be some variability in age assessments based on estimated diaphyseal length, it is clear that a substantial number of infants and young children were underrepresented in the Fairty ossuary demography as a result of methodological bias. It should be noted, however, that the inclusion of these individuals does not increase the overall MNI calculated by Anderson (1964), which were derived from counts of mastoid processes.

CONCLUSIONS

Given the potentially rich source of demographic information available in southern Ontario, a number of studies (e.g., Montgomery, 1886; Hammond, 1923; McIlwraith, 1946, 1947; Kidd, 1953; Churcher and Kenyon, 1960; Anderson, 1964; Katzenberg and White, 1979; Pfeiffer, 1974, 1983; Jerkic, 1975; Saunders, 1977; Hartney, 1978; Molto, 1983; Patterson, 1984; Jackes, 1986; Mullen, 1990; Mullen and Hoppa, 1992; Gruspier, 1996) have focused on skeletal samples derived from ossuaries.

> "The Ontario Iroquois ossuaries, especially those of the Huron, are particularly amenable to demographic analysis because, due to historical accident, the problems of sample size and chronological control do not apply" (Katzenberg and White, 1979:11).

Although there has been some recent criticism of the exact degree of chronological control we can assume for large ossuaries (Sutton, 1988), they still represent a potentially valuable source for demographic analysis because of the sheer quantity of material available. However, in some earlier analyses, much of the fragmentary bone was considered unanalyzable and was not included in the resultant demographic profiles. In the case of southern Ontario ossuaries, the method of interment, which promotes increased fragmentation of bones, may contribute to the inaccurate representation of the subadult demographic profile. As Young and Varley (1992) note, during the later period of ossuary evolution in southern Ontario, there is a shift in structure of the ossuary from the maintenance of individual burials to the thorough mixing of bones. The following ethnohistoric account illustrates the potential for fragmentation of bones as a direct result of the manipulation of the remains in the ossuary during the ceremony of the Feast of the Dead.

> "The bones were to be thrown into the pit at daybreak. . . .emptying the packages into the pit but keeping the robes in which the bones were wrapped. Five or six in the pit arranged the bones with poles as they were thrown in" (Thwaites, 1896–1901:vol 10: 299).

Although the lack of inclusion of fragments may have less effect on the adult demography, a subadult fragment may represent a substantial portion of a single bone—the equivalent of a single individual. It is clear from this study that the exclusion of frag-

mentary remains can have drastic effects on paleodemographic reconstructions. As we recognize the potential error inherent in making individual estimates from regression equations, the mortality distribution we present represents not absolute age cohorts, but rather the impact on palaeodemography of omitting fragmentary skeletal elements. Whether infants are underrepresented because of fragmentation or omission from the sample, there will still always be subadult fragmentary remains which cannot be aged without some method of estimating their complete lengths. This study provides a technique for this purpose with regression equations for measures of proximal and distal shaft-end breadths used to estimate diaphyseal length.

ACKNOWLEDGMENTS

We thank Jerry Melbye and Susan Pfeiffer for providing access to the Kleinburg and Uxbridge ossuary material, respectively. Our thanks also to Shelley Saunders, Mike Spence, and David Begun for their comments on an earlier version of this manuscript. This research was supported in part by the Ontario Heritage Foundation (Grant ARG-550, to K.L.G.) and the Social Sciences and Humanities Research Council of Canada (Doctoral Fellowship (752-93-3058, to R.D.H.).

LITERATURE CITED

Anderson JE (1964) The people of Fairty: An osteological analysis of an Iroquois ossuary. In: Contributions to Anthropology 1961–62, Part 1. Ottawa: National Museum of Canada Bulletin *193:*28–129.

Brown D, and Rothery P (1993) Models in Biology: Mathematics, Statistics and Computing. Toronto: John Wiley & Sons.

Churcher CS, and Kenyon WA (1960) The Tabor Hill ossuaries: A Study in Iroquois Demography. Hum. Biol. *32:*249–273.

Gruspier KL (1994) Infectious disease and porotic hyperostosis in an 8th to 12th century Italian town. Am. J. Phys. Anthropol. Suppl. *18:*98.

Gruspier KL (1996) Weaning Age in Southern Ontario Iroquois Skeletal Population Samples: Quantification of Dental Attrition by Digital Imaging. Ph.D. Thesis, Department of Anthropology, University of Toronto, Ontario.

Gruspier KL, and Hoppa RD (1993) Estimation of diaphyseal length from fragmentary nonadult remains. Am. J. Phys. Anthropol. Suppl. *16:*100.

Hamilton LC (1992) Regression With Graphics. Pacific Grove, CA: Brooks/Cole Publishing Company.

Hammond JN (1923) Exploration of the Ossuary Burials of the Huron Nation, Simcoe County. Annual Archaeological Report Ontario. Toronto: Royal Toronto Museum, pp. 95–102.

Hartney P (1978) Palaeopathology of Archaeological Aboriginal Populations from Southern Ontario and Adjacent Region. Ph.D. Thesis, Department of Anthropology, University of Toronto, Ontario.

Hoffman JM (1979) Age estimation from diaphyseal lengths: Two months to twelve years. J. Forensic Sci. *24:*461–469.

Hoppa RD (1991) A Comparative Study of Long Bone Growth and Development from the Skeletal Remains of Romano-British and Medieval Populations. M.Sc. Thesis, Department of Archaeology and Prehistory, University of Sheffield, and Department of Archaeological Sciences, University of Bradford.

Hoppa RD (1992) Evaluation human skeletal growth: An Anglo-Saxon example. Int. J. Osteoarchaeol. *2:*275–288.

Hoppa RD (1996) Representativeness and Bias in Cemetery Samples: Implications for Paleodemographic Reconstructions of Past Populations. Ph.D. Thesis, Department of Anthropology, McMaster University, Hamilton, Canada.

Jackes M (1986) The mortality of Ontario archaeological populations. Can. Rev. Phys. Anthropol. *5:*33–48.

Jackes M (1994) Birth rates and bones. In A Herring and L Chan (eds.): Strength in Diversity: A Reader in Physical Anthropology. Toronto: Canadian Scholars Press Inc., pp. 155–185.

Jerkic SM (1975) The Analysis of Huron Skeletal Biology and Mortuary Practices: The Maurice Ossuary. Ph.D. Thesis, Department of Anthropology, University of Toronto, Ontario.

Johnston FE (1962) Growth of the long bones of infants and young children at Indian Knoll. Am. J. Phys. Anthropol. *20:*249–254.

Johnston FE, and Zimmer LO (1989) Assessment of growth and age in the immature skeleton. In MY İşcan and KAR Kennedy (eds.): Reconstruction of Life From the Skeleton. New York: Alan R. Liss, pp. 11–21.

Kapches M (1976) The interment of infants of the Ontario Iroquois. Ont. Archaeol. *27:*29–39.

Kapches M (1981) The Middleport Pattern in Ontario Iroquoian Prehistory. Ph.D. Dissertation, University of Toronto.

Katzenberg MA, and White R (1979) A palaeodemographic analysis of the os coxae from Ossossoné Ossuary. Can. Rev. Phys. Anthropol. *1:*10–28.

Kenyon I, and Kenyon T (1983) Comments on the 17th Century Glass Trade Beads from Ontario. In CF Hayes (ed): Proceedings of the 1982 Glass Trade Bead Conference. Research Records No. 16. Rochester: Rochester Museum and Science Center.

Kidd KE (1953) The excavation and historical identification of a Huron ossuary. Am. Antiq. *18:*359.

Larocque R (1991) Une Étude Ethnohistorique et Paléoanthropoligique des Epidémies en Huronie. Ph.D. Dissertation, Université de Montréal.

Lovejoy CO, Russell KF, and Harrison ML (1990) Long bone growth velocity in the Libben population. Am. J. Hum. Biol. *2:*533–541.

Patterson DK (1984) A Diachronic Study of Dental Paleopathology and Attritional Status of Prehistoric Ontario Pre-Iroquois and Iroquois Populations. National

Museum of Man Mercury Series, Archaeological Survey of Canada, Paper No. 122, Ottawa.

McIlwraith TF (1946) Archaeological work in Huronia, excavation near Warminster. Can. Hist. Rev. *December:*394–401.

McIlwraith TF (1947) On the location of Cahiague. Trans. R. Soc. Can. Ser. 2 Sect. II *XLI:*99.

Melbye FJ (1984) Fertility and mortality among Iroquoian people of the 14th century: The Fairty ossuary revisited. Unpublished manuscript.

Merchant VL, and Ubelaker DH (1977) Skeletal growth of the protohistoric Arikara. Am. J. Phys. Anthropol. *46:*61–72.

Miles AEW, and Bulman JS (1994) Growth curves of immature bones from a Scottish island population of sixteenth to mid-nineteenth century: Limb bone diaphyses and some bones of the hand and foot. Int. J. Osteoarchaeol. *4:*121–136.

Molleson TI (1989) Social implications of mortality patterns of juveniles from Poundbury Camp, Romano-British Cemetery. Anthropol. Anz. *47:*27–38.

Molto JE (1983) Biological Relationships of Southern Ontario Woodland Peoples: The Evidence of Discontinuous Cranial Morphology. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper No. 117, Ottawa.

Montgomery H (1886) Report on an Ossuary From Markham County, 1881. The Indian, Hagersville Haldimand Company, pp. 102.

Mullen GJ (1991) Human Osteology of the Warminster Site (BdGv-1) Ossuary. M.A. Thesis, Department of Anthropology, University of Toronto, Ontario.

Mullen GJ, and Hoppa RD (1992) Rogers Ossuary (AgHb-131): An early Ontario Iroquois burial feature from Brantford Township. Can. J. Archaeol. *16:*32–47.

Norušis (1993) SPSS for Windows Base System User's Guide Release 6.0. Chicago: SPSS Inc.

Pfeiffer S (1974) A palaeodemographic study of the Kleinburg people. Paper presented to the Third Annual Meeting of the Canadian Association for Physical Anthropology, Peterborogh.

Pfeiffer S (1980) Spatial distribution of human skeletal material within an Iroquoian ossuary. Can. J. Archaeol. *4:*169–171.

Pfeiffer S (1983) Demographic parameters of the Uxbridge ossuary population. Ont. Archaeol. *40:*9–14.

Pfeiffer S (1984) Paleopathology in an Iroquoian ossuary, with special reference to tuberculosis. Am. J. Phys. Anthropol. *65:*181–189.

Ribot I, and Roberts C (1996) A study of non-specific stress indicators and skeletal growth in two medieval subadult populations. J. Archaeol. Sci., *231:*67–79.

Saunders SR (1978) The Development and Distribution of Discontinuous Morphological Variation of the Human Infracranial Skeleton. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper No. 81, Ottawa.

Saunders SR (1992) Subadult skeletons and growth related studies. In SR Saunders and MA Katzsenberg (eds.): Skeletal Biology of Past Peoples: Research Methods. New York: Wiley-Liss, Inc. pp. 1–20.

Saunders SR, and Spence MW (1986) Dental and skeletal age determinations of Ontario Iroquois infant burials. Ont. Archaeol. *46:*45–54.

Saunders SR, and Melbye FJ (1990) Subadult mortality and skeletal indicators of health in late Woodland Ontario Iroquois. Can. J. Archaeol. *14:*61–74.

Saunders SR, and Hoppa RD (1993) Growth deficit in survivors and non-survivors: Biological mortality bias in subadult skeletal samples. Yearb. Phys. Anthropol. *36:*127–151.

Saunders SR, Hoppa RD, and Southern RA (1993) Diaphyseal growth in a 19th century skeletal sample of subadults from St. Thomas' Church, Belleville, Ontario. Int. J. Osteoarchaeol. *3:*265–281.

Simmons T, Jantz RL, and Bass WM (1990) Stature estimation from fragmentary femora: A revision of the Steele method. J. Forensic Sci. *35:*628–636.

Steele DG, and McKern TW (1969) A method for assessment of maximum long bone length and living stature from fragmentary long bones. Am. J. Phys. Anthropol. *31:*215–228.

Stewart TD (1954) Evaluation of evidence from the skeleton. In RBH Gradwohl (ed.): Legal medicine. St. Louis: C.V. Mosby, pp. 407–450.

Sundick RI (1978) Human skeletal growth and age determination. Homo *29:*228–249.

Sutton RE (1988) Palaeodemography and late Iroquoian ossuary samples. Ont. Archaeol. *48:*42–50.

Thwaites RG (ed.) (1896–1901) Jesuit Relations and Allied Documents. Cleveland: Burrows.

Ubelaker DH (1987) Estimating age at death from immature human skeletons: An overview. J. Forensic Sci. *32:*1254–1263.

Ubelaker DH (1989) Human Skeletal Remains: Excavation, Analysis, Interpretation. Washington: Taraxacum.

Walker PL (1969) The linear growth of long bones in late Woodland Indian children. Proc. Ind. Acad. Sci. *78:*83–87.

Wall CE (1991) Evidence of weaning stress and catch-up growth in the long bones of a central California Amerindian sample. Ann. Hum. Biol. *18:*9–22.

Wood JW, Milner GR, Harpending HC, and Weiss KM (1992) The osteological paradox: Problems of inferring prehistoric health from skeletal samples. Curr. Anthropol. *33:*343–370.

Young PM, and Varley C (1992) Feasts, furs, and tournaments: Interpreting transformations in Huron ossuaries. Paper presented at the McMaster Anthropological Society Annual Symposium, Hamilton, Ontario.